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Serial: 5701-BLL-82-329

Attention: W. R. McIntosh

Subject: Field Support for Solar Tracker

References:
1. Contract NAS8-34681, dated 9 November 1981
2. AP-74-84029 Report to W. R. McIntosh, dated 6 December 1981
3. BASD-MO 6441, Final Summary Report for Breadboard Model Solar Correlation Tracker and Simulator

Gentlemen:

This letter documents the effort and findings under the effort expended for Contract NAS8-34681. Contained herein are the objectives, program description, test results, and recommendation for further activities.

INTRODUCTION

On 9 November 1981, Bendix received a field support contract from NASA for the purpose of performing concept demonstration tests with the Solar Telescope and Tracker supplied under a previous procurement. As these tests were weather dependent the period of performance was extended from 6 January 1982, to 31 July 1982.

This report defines the objectives, describes preparation and analysis prior to test, a summary of test results, and a closed loop analysis of the gimbal and tracker system, and finally recommendations for future activities are given.

OBJECTIVES

The primary objectives of this task were to:

- Demonstrate the capability of stabilizing the image produced by a science camera (co-located in the Solar Telescope) by remote and non-mechanical means.

o Provide analysis of tracker gimbal and optics to determine if further optimization is required.

PROGRAM DESCRIPTION

In a technical discussion held at NASA in January 1981, a plan was established for the conduct of this program. It was mutually decided at that time to use a science camera, similar to the camera (Sensor) employed in the Solar Tracker, for the experimental investigation.

A preliminary definition was made of the installation and interface requirements. The major interface was that of transferring the image stabilization signals to the science camera, with appropriate gain and linearity. In the current installation the tracker (in the track mode) scans an area slightly larger than a sunspot diameter, which is on the order of a few mils (sensor displacement). The total image area diameter available is on the order of 700 mils. Because of this fact, the track scan area can be positioned anywhere in the total available sensor region as depicted in Figure 1.

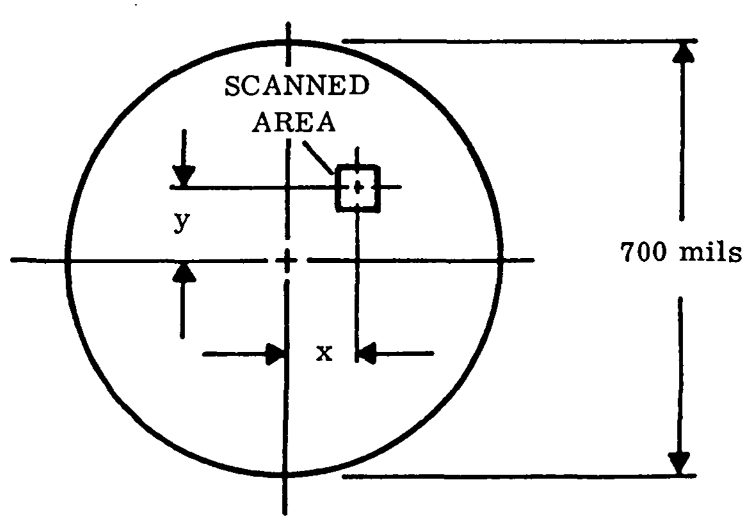

FIGURE 1 - SCAN AREA

This is exactly what happens when image motion is induced by wind loading or whatever reason. That is without a stabilizing element the solar area of interest is free to move with respect to the sensor active region. If a stabilizing (mechanical) mechanism is employed, this image motion can be measured and removed from the track sensor. This is accomplished by using the tracker error outputs to position a refractory optical element. Another way to accomplish this is by stabilizing the entire telescope with an electrical mechanical servo control system. This second method requires much more power and weight than a servoed optical element.

A third and more efficient way to stabilize the image presented to the science camera is to use a quasi-closed loop technique which does not utilize any mechanical motion. This method is the one which was evaluated in this program. In this method the solar tracker is caused to lock-on and track a sunspot anywhere on its image area (no stabilizing element). The scanned area (during track) can be anywhere in the overall sensor area. The errors signals generated (x, y, on Figure 1) are applied to the deflection system of a co-located camera, such that a raster scan area is made to remain stationary on the viewing screen (i.e., image motion is subtracted from the image sensed by the co-located camera). Within limits, the co-located camera could view a portion of the sun, offset from the track point of the tracker. In the case of a co-located camera that scans its entire sensing area, edges of the sensing area would show up in the displayed image. This should not be objectionable as long as the area of interest remains stationary.

TEST SET-UP AND RESULTS

The test set-up for this experiment is shown in Figure 2. The image is coupled to the tracker through a beam splitter. The reflected image from the beam splitter is then applied to the Science Camera (co-located sensor) via a mirror.

A common raster scan generator drives the tracker sensor, the co-located sensor, display #1, and display #2.

As the image presented to the tracker moves (for whatever reason) the scanned area on the tracker display 1 moves about with respect to the center. However, the image on display 2 remains stationary.

In the actual experiment, image motion was induced such that the tracker scan area traversed the entire scan area of display 1. During this time no image motion was observed on display 2. No quantified data was taken at this time; however, the experiment demonstrates the feasibility of this approach.

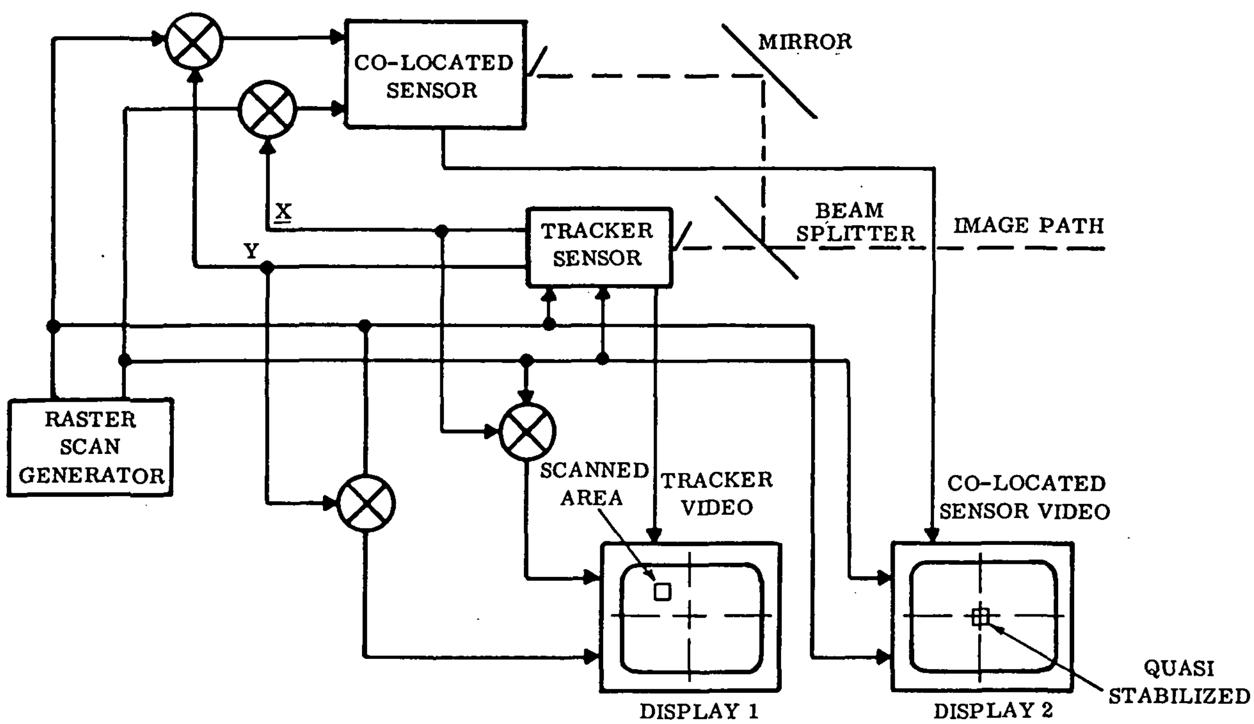

FIGURE 2. TEST SET-UP

TRACKER-GIMBAL STABILIZATION LOOP CONSIDERATIONS

A second task for this contract was to examine the closed loop performance of the tracker, gimbal, and optical element. Precise definition of current gain parameters are not available; however, the results should be representative of the actual hardware which was initially defined in References 1 and 3. A significant change to the original system was the removal of the flex pivots (which were used for a return to zero capability) and the addition of feedback potentiometer to provide a position mode.

The system response is examined in the paragraphs to follow:

<u>Gimbal Servo and Electronics</u>

The transfer function of the torque motor, gimbal, amplifier, and load (inertial) can be derived from Figure 3.

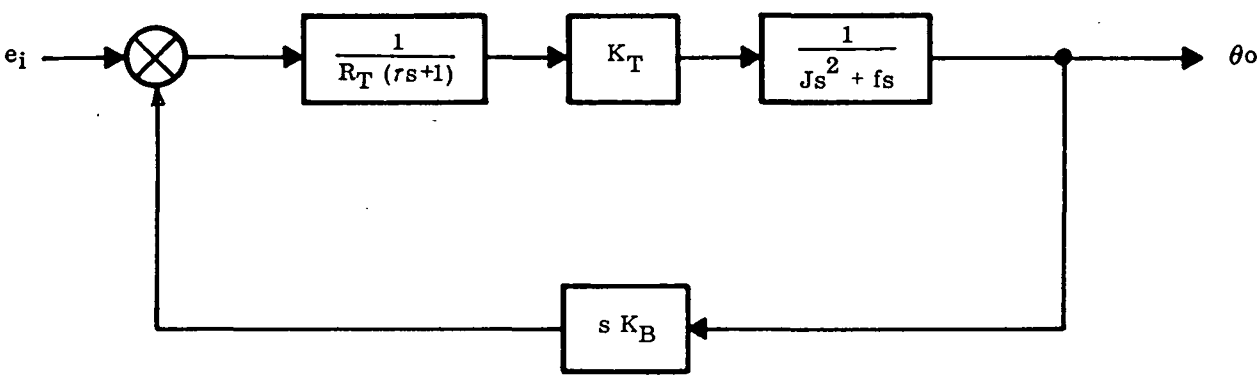

FIGURE 3 - GIMBAL TRANSFER FUNCTION

The parameters for this diagram are given in Table 1 for both the inner and outer gimbal.

TABLE 1

<u>Parameter</u>	<u>Inner</u>	<u>Outer</u>
R_T $(R_L + R_S)$	90 ohm	76 ohm
K_B (EMF)	.027 V/rad/sec	.13 V/rad/sec
J (Total Inertia)	.263 gr-cm-sec^2	4.69 gr-cm-sec^2
F (Assumed 0)	nil	nil
τ (Elect. Time Constant)	1×10^{-4} sec	1.5×10^{-3} sec
K_T (Torque Constant)	275 gr-cm/amp	1296 gr-cm/amp

The inner and outer gimbal closed loop transfer functions are:

$$G_1\ (S) = \frac{1}{K_B}\ \left(\frac{1}{S}\right)\left(\frac{1}{\frac{JL}{K_T K_B}\ S^2 + \frac{LF+JR}{K_T K_B}}\right) S + 1 \qquad (1)$$

Note that LF << JR and $\frac{L}{R} << \frac{JR}{K_B K_T}$

where $\frac{L}{R}$ = electrical time constant

$\frac{JR}{K_B K_T}$ = mechanical time constant

Equation (1) can be simplified to

$$G_1\ (S) = \frac{1}{K_B}\ \left(\frac{1}{S}\right)\left(\frac{1}{\left(\frac{JR}{K_B K_T}\ S + 1\right)\left(\frac{L}{R}\ \ S + 1\right)}\right) \qquad (2)$$

$$\text{Inner Loop } G_1(S)_i = \frac{37}{S\ (3.19\ S + 1)(.0001\ S + 1)} \qquad (3)$$

$$\text{Outer Loop } G_1(S)_o = \frac{7.7}{S\ (2.1\ S + 1)(1.5 \times 10^{-3}\ S + 1)} \qquad (4)$$

The overall gimbal transfer function is defined by the diagram of Figure 4.

The closed loop transfer functions for inner and outer control loops with rate and position feedback are derived as follows:

$$\text{Let } K_c + K_a K_g\ S = K_c\ \left(1 + \frac{K_a K_g}{K_c}\ S\right) \qquad (5)$$

The inner gimbal open loop transfer function is:

$$G_I(S)_{O.L.} = \frac{37\ K_p\ (K_c)\left(1 + \left(\frac{K_a K_g}{K_c}\right)\ S\right)}{S\ (3.19\ S + 1)(1 \times 10^{-Y}\ S + 1)} \qquad (6)$$

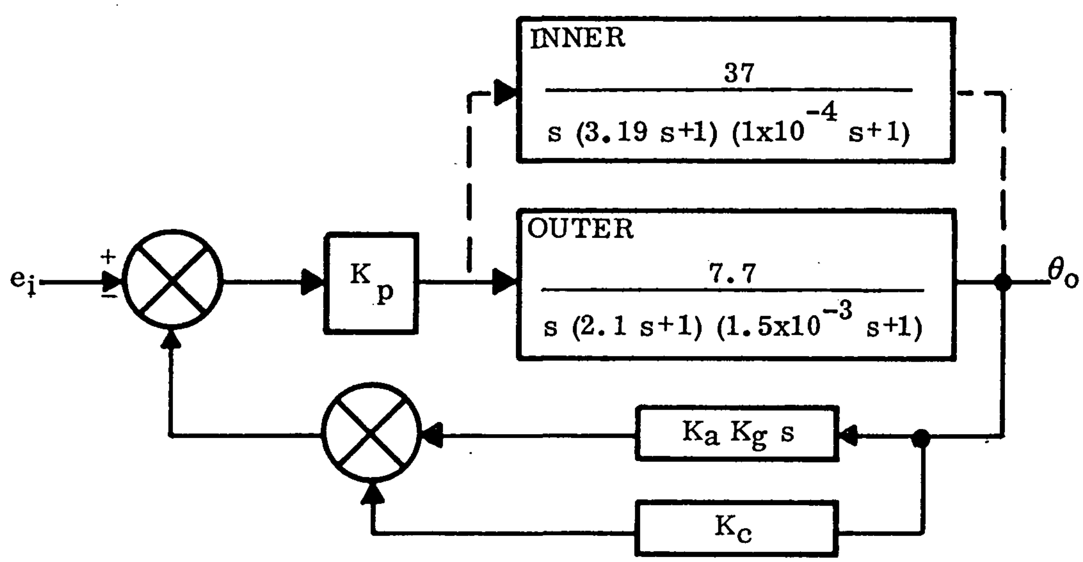

FIGURE 4 - OVERALL GIMBAL BLOCK DIAGRAM

The following parameters were selected for the constants in Equation (6).

Let $37\ K_pK_c = 8 \times 10^5$

$K_pK_c = 2.2 \times 10^4$

$K_p = 150$

Selecting $K_c = 150$

Given $K_g = .031$

$\frac{K_aK_g}{K_c} = .01$ than $K_a = 48$

$$G_I(S)_{O.L.} = \frac{8 \times 10^5\ (1 + .01S)}{A\ (3.19\ S + 1)(1 \times 10^{-4}\ S + 1)} \quad \text{(Inner Open Loop)} \qquad (7)$$

The closed loop response is:

$$G_I(S)_{C.L.} = \frac{57.3\ (5.55 \times 10^3)}{3.2 \times 10^{-4}\ S^3 + 3.2\ S^2 + 8000S + 8 \times 10^5} \quad (°/V) \qquad (8)$$

Figure 5 shows the closed loop response of the system for both the inner and outer loops.

For the outer gimbal loop the open loop transfer function is:

$$G_o(S)_{O.L.} = \frac{7.7\ K_c K_p\ (1 + \frac{K_a K_g}{K_c})\ S}{S\ (2.1\ \ S + 1)(1.5 \times 10^{-3}\ S + 1)} \qquad (9)$$

Let $7.7\ K_p K_c = 1 \times 10^5$

$K_p K_c = 1.3 \times 10^4$

$K_p = 1.50$

$K_c = 87$

$K_g = .031$

$\frac{K_a K_g}{K_c} = .04$

Then $K_a = \frac{.04}{.031}\ (87) = 112$

Tracker

The solar tracker transfer function block diagram is shown in Figure 6.

The required tracker response (bandwidth) is 50 Hz. The gain parameters are:

$K_e = 2.5$ mV/mil

$K_D = 1.33$ mV/mil

$K_T(S) = \frac{1}{S}\ (96)$

Note the present gain of $(S\text{-}19;\ S\text{-}20)^3 K_T$ is approximately 96 V/V. The frequency response of the system is equal to

$$f = \frac{K_E K_T K_D}{2\pi} = 50 \text{ hertz} \qquad (12)$$

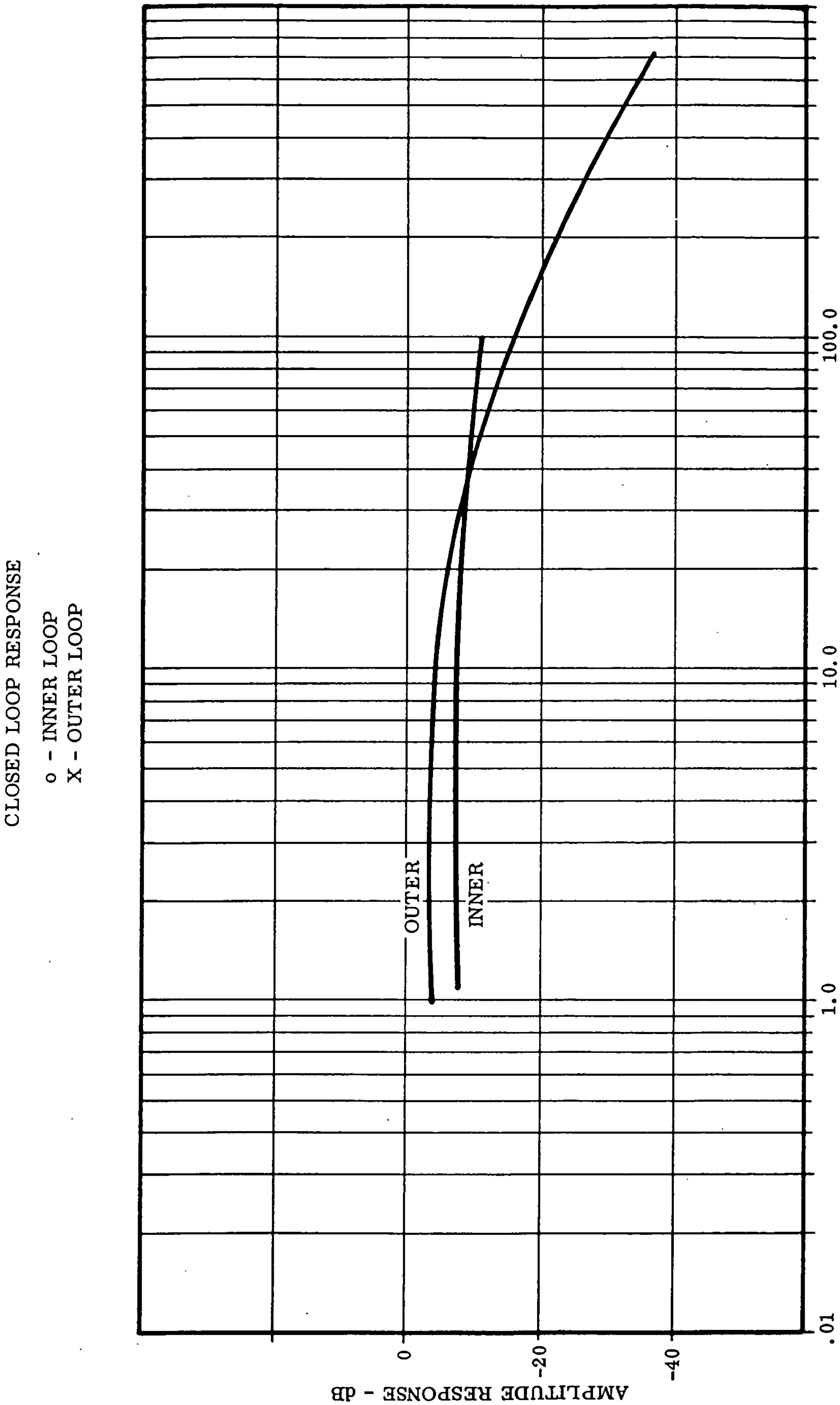

FIGURE 5 - jω RAD/SEC

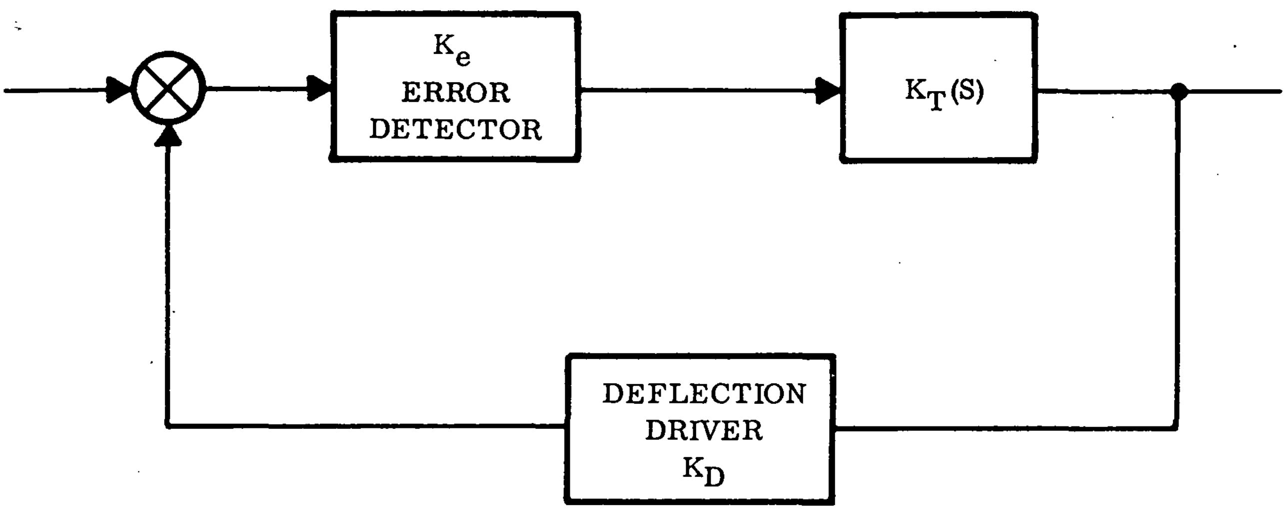

FIGURE 6 - SOLAR TRACKER TRANSFER FUNCTION BLOCK DIAGRAM

A higher response can be achieved by increasing the gain (K_T). The closed loop tracker is inherently stable and has a transfer function.

$$G_T(S) = .75 \left(\frac{1}{.003\ S + 1}\right)$$

In Figure 7 (D_i) is the image displacement on the tracker sensor. K_r represents the displacement due to refraction of a glass rotated in the image plane. The refraction coefficient of the glass (B_k 7) is 1.517. It is desired to drive d_s (image motion at detector) to zero for proper image stabilization. In a practical sense, the error must be kept to less than 10% of the system resolution which is 1 mil (d_s = .1 mil). A .1 mil displacement or less requires a static gain of 9. The static gain (Figure 7) is

$$K_I (.75\ V/mil)(.4^o/V)(5.6\ mil/0) = 9 \quad (13)$$

$$K_I \quad 5.4$$

Since the response of the gimbal is similar to that described in the reference, a similar compensation network is recommended.

$$G_{comp} = \frac{.01S + 1}{.02S + 1}$$

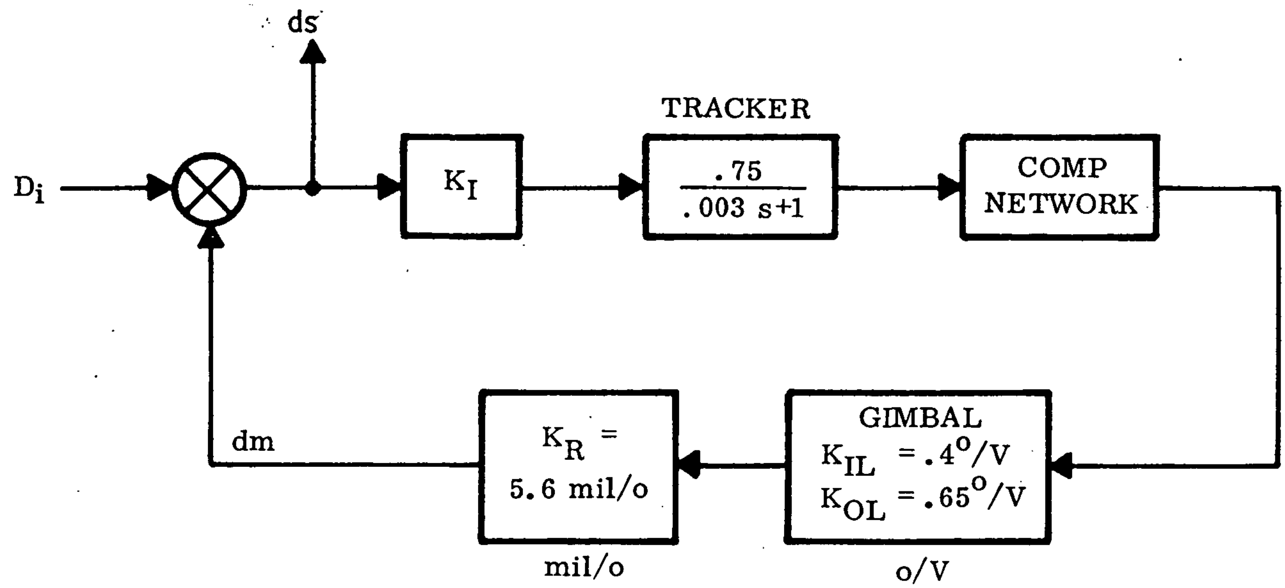

FIGURE 7 - SYSTEM DIAGRAM

Additional gain may be added to the system loop if required to attain a higher frequency response. A more detailed analysis would require that the parameters be defined more precisely.

RECOMMENDATIONS

The results of the experimental testing performed 24 June 1982 clearly indicate the feasibility of the Quasi-stabilized approach. However, it would be useful to study the implications when applied to other sensors (CCD, SEC Vidicons, etc.) to determine if a hybrid system of sensors could be utilized.

It also appears that the current Solar Tracker is in its last useful stages of life. The system was designed and fabricated in December 1972 and was designed primarily as a laboratory instrument to be used in a feasibility demonstration.

During that time the tracker has been installed in a Solar Instrument at the Big Bear Lake Observatory (operated by Cal Tech). In the summer of 1979, it was installed in the observatory at MSFC and has been exposed to the elements ever since. As a result, connections and contacts have suffered corrosion and are becoming intermittent. It is therefore recommended that a new tracker, utilizing current technology, be designed and fabricated and installed in the MFSC observatory.

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cc:
NASA/AS24D (5)
NASA/AT01 (1)
NASA/EM12B-06/Gray (1)
NASA/EC22/McIntosh (5)